AN UPDATE ON BLAST FURNACE GRANULAR COAL INJECTION

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ABSTRACT

A blast furnace coal injection system has been constructed and is being used on the furnaces at the Burns Harbor Division of Bethlehem Steel. The injection system was designed to deliver both granular (coarse) and pulverized (fine) coal. Construction was completed on schedule in early 1995. Coal injection rates on the two Burns Harbor furnaces were increased throughout 1995 and was over 200 lbs/ton on C furnace in September. The injection rate on C furnace reached 270 lbs/ton by mid-1996. A comparison of high volatile and low volatile coals as injectants shows that low volatile coal replaces more coke and results in a better blast furnace operation. The replacement ratio with low volatile coal is 0.96 lbs coke per pound of coal. A major conclusion of the work to date is that granular coal injection performs very well in large blast furnaces. Future testing will include a processed sub-bituminous coal, a high ash coal and a direct comparison of granular versus pulverized coal injection.

I. INTRODUCTION

A blast furnace coal injection system has been installed at the Burns Harbor Division of Bethlehem Steel Corporation. This is the first blast furnace coal injection system in the US that has been designed to deliver granular (coarse) coal - all previously installed blast furnace coal injection systems in the US have been designed to deliver pulverized (fine) coal. Financial assistance for the coal injection system was provided by the Clean Coal Technology Program.

The use of granular coal in blast furnaces was jointly developed by British Steel and Simon-Macawber (now CPC-Macawber) and used at the Scunthorpe Works in England. The blast furnaces at Scunthorpe have about one-half the production capability of the Burns Harbor blast furnaces. Therefore, one of the main objectives of the Clean Coal Technology (CCT) test program at Burns Harbor is to determine the effect of granular coal injection on large high productivity blast furnaces. Another objective of the CCT test program at Burns Harbor is to determine the effect of different types of US coals on blast furnace performance.

The Burns Harbor Plant produces flat rolled steel products for the automotive, machinery and construction markets. The Plant is located on the southern shore of Lake Michigan about 30 miles east of Chicago. Burns Harbor is an integrated operation that includes two coke oven batteries, an iron ore sintering plant, two blast furnaces, a three vessel BOF shop and two twin-strand slab casting machines. These primary facilities can produce over five million tons of raw steel per year. The steel finishing facilities at Burns Harbor include a hot strip mill, two plate mills, a cold tandem mill complex and a hot dip coating line.

When originally designed and laid-out, the Burns Harbor Plant could produce all the coke required for the two blast furnaces operating at 10,000 tons/day. However, improved practices and raw materials have resulted in a blast furnace operation that now can produce over 14,000 tons/day. Since the coke oven batteries are not able to produce the coke required for a 14,000 ton/day blast furnace output, other sources of coke and energy have been used to fill the gap. Over the years, coke has been shipped to Burns Harbor from other Bethlehem plants and from outside coke suppliers. In addition, auxiliary fuels have been injected into the furnaces to reduce the coke requirements. The auxiliary fuels have included coal tar, fuel oil and natural gas. The most successful auxiliary fuel through the 1980s and early 1990s has been natural gas. It is easy to inject and, at moderate injection levels, has a highly beneficial effect on blast furnace operations and performance. However, there are two significant problems with the use of natural gas in blast furnaces. One problem is the cost and the other is the amount that can be injected and, therefore, the amount of coke that can be replaced. Our process and economic studies showed that more coke could be replaced and iron costs could be reduced by injecting coal instead of natural gas in the Burns Harbor furnaces.

This led Bethlehem to submit a proposal to the DOE to conduct a comprehensive assessment of coal injection at Burns Harbor. Following an extensive review by the DOE, Bethlehem's Blast Furnace Granular Coal Injection System Demonstration Project was one of thirteen demonstration projects accepted for funding in the Clean Coal Technology Program third round of competition. The primary thrust of the project is to demonstrate commercial performance characteristics of granular coal as a supplemental fuel for steel industry blast furnaces. The technology will be demonstrated on large high productivity blast furnaces using a wide range of coal types available in the US. The planned tests will assess the impact of coal particle size distribution as well as chemistry on the amount of coal that can be injected effectively. Upon successful completion of the work, the results will provide the information and confidence needed by others to assess the technical and economic advantages of applying the technology to their own facilities.

A major consideration in evaluating coal injection in the US is the aging capacity of existing cokemaking facilities and the high capital cost to rebuild these facilities to meet emission guidelines under the Clean Air Act Amendments. The increasingly stringent environmental regulations and the continuing decline in domestic cokemaking capability will cause significant reductions in the availability of commercial coke over the coming years. Due to this decline in availability and increase in operating and maintenance costs for domestic cokemaking facilities, commercial coke prices are projected to increase by more than general inflation. Higher levels of blast furnace injectants, such as coal, enable domestic integrated steel producers to minimize their dependence on coke.

Blast Furnace Process

The ironmaking blast furnace is at the heart of integrated steelmaking operations. As shown in Figure 1, the raw materials are charged to the top of the furnace through a lock hopper arrangement to prevent the escape of pressurized hot reducing gases. Air needed for the combustion of coke to generate the heat and reducing gases for the process is passed through stoves and heated to 1500-2300ºF. The heated air (hot blast) is conveyed to a refractory-lined bustle pipe located around the perimeter of the furnace. The hot blast then enters the furnace through a series of ports (tuyeres) around and near the base of the furnace. The molten iron and slag are discharged through openings (tapholes) located below the tuyeres. The molten iron flows to refractory-lined ladles for transport to the basic oxygen furnaces.

A schematic showing the various zones inside the blast furnace is shown in Figure 2. As can be seen, the raw materials, which are charged to the furnace in batches, create discrete layers of ore and coke. As the hot blast reacts with and consumes coke at the tuyere zone, the burden descends in the furnace resulting in a molten pool of iron flowing around unburned coke just above the furnace bottom (bosh area). Reduction of the descending ore occurs by reaction with the rising hot reducing gas that is formed when coke is burned at the tuyeres.

The cohesive zone directly above the tuyeres is so called because it is in this area that the partially reduced ore is being melted and passes through layers of coke. The coke layers provide the permeability needed for the hot gases to pass through this zone to the upper portion of the furnace. Unlike coal, coke has the high temperature properties needed to retain its integrity in this region and is the reason that blast furnaces cannot be operated without coke in the burden.

The hot gas leaving the top of the furnace is cooled and cleaned. Since it has a significant heating value (80-100 Btu/scf), it is used to fire the hot blast stoves. The excess is used to generate steam and power for other uses within the plant.

II. COAL INJECTION TECHNOLOGY

Bethlehem decided to utilize the CPC Macawber Blast Furnace Granular Coal Injection (BFGCI) System, because unlike more widely used systems that utilize only pulverized coal, it is capable of injecting both granular and pulverized coal. Bethlehem believes that the CPC Macawber system offers a variety of technical and economic advantages which make this system potentially very attractive for application in the US basic steel industry. A schematic showing the application of the technology to the blast furnace is shown in Figure 3. Some of the advantages of this technology include:

FIGURE 1

THE BLAST FURNACE COMPLEX

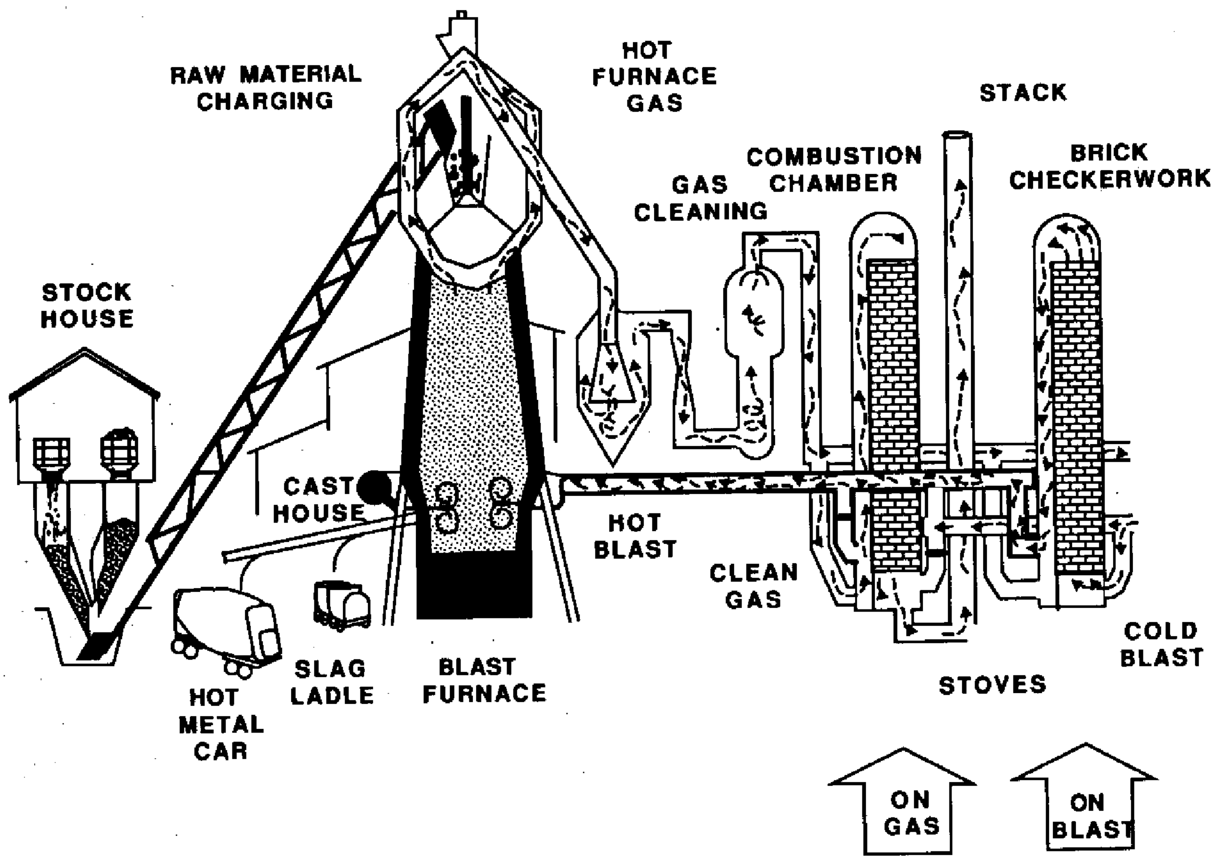


FIGURE 2

ZONES IN THE BLAST FURNACE

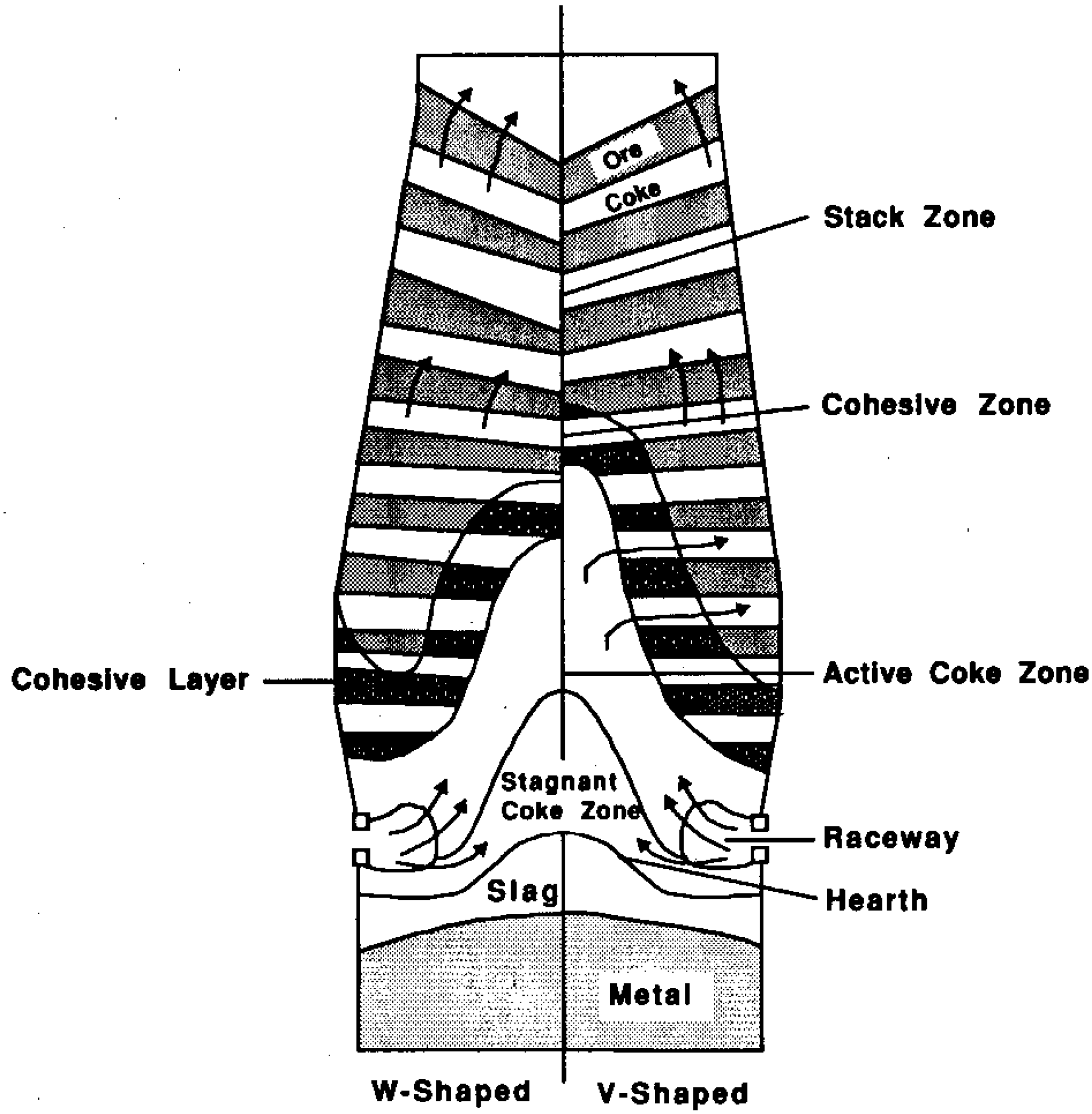
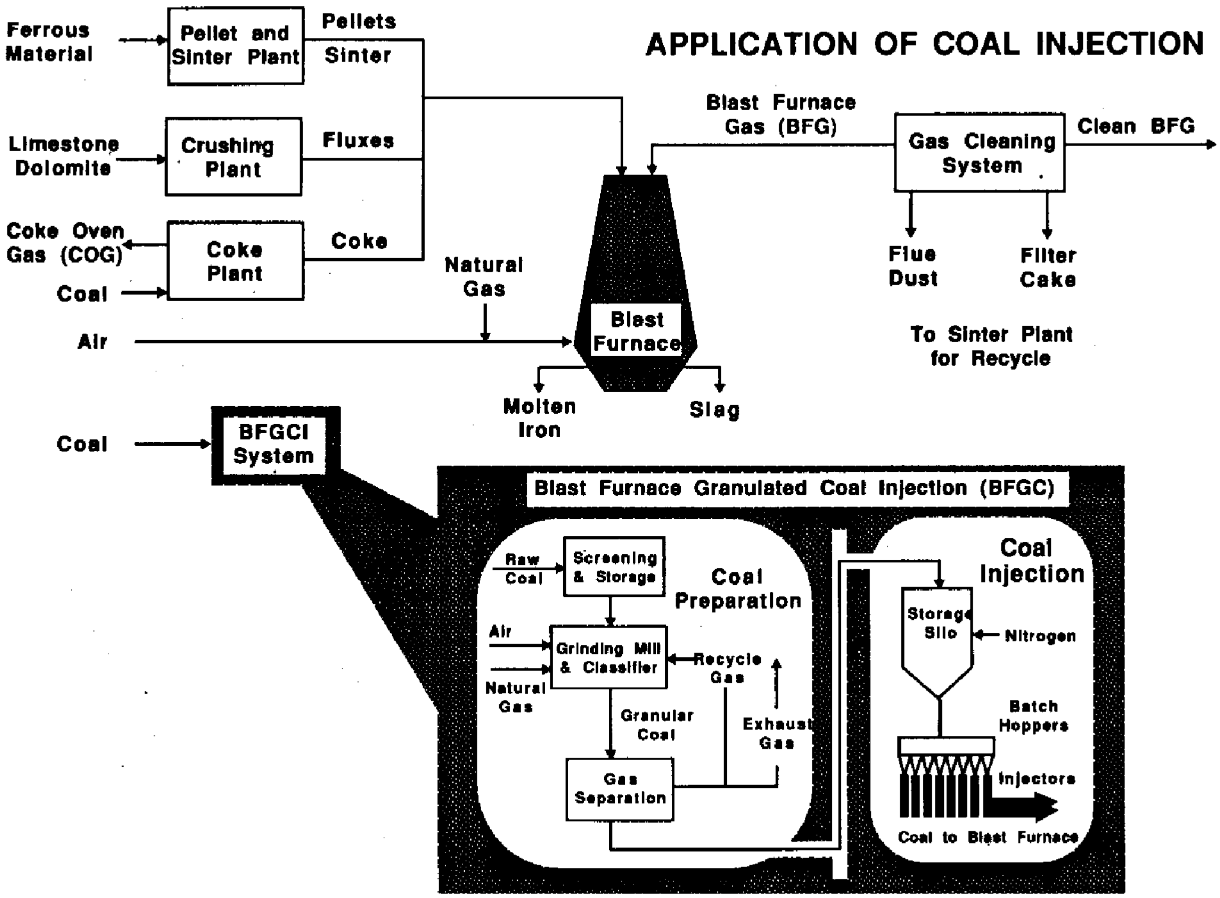


FIGURE 3

APPLICATION OF COAL INJECTION



- The injection system has been used with granular coal as well as with pulverized coal. No other system has been utilized over this range of coal sizes. Granular coal is 10-30% minus 200 mesh whereas pulverized coal is 70-80% minus 200 mesh.

- The costs for granular coal preparation systems are less than those for the same capacity pulverized coal systems.

- Granular coal is easier to handle in pneumatic conveying systems. Granular coals are not as likely to stick to conveying pipes if moisture control is not adequately maintained.

- Coke replacement ratios obtained by British Steel have not been bettered in any worldwide installation.

- System availability has exceeded 99 percent during several years of operation at British Steel.

- The unique variable speed, positive displacement CPC Macawber injectors provide superior flow control and measurement compared to other coal injection systems.

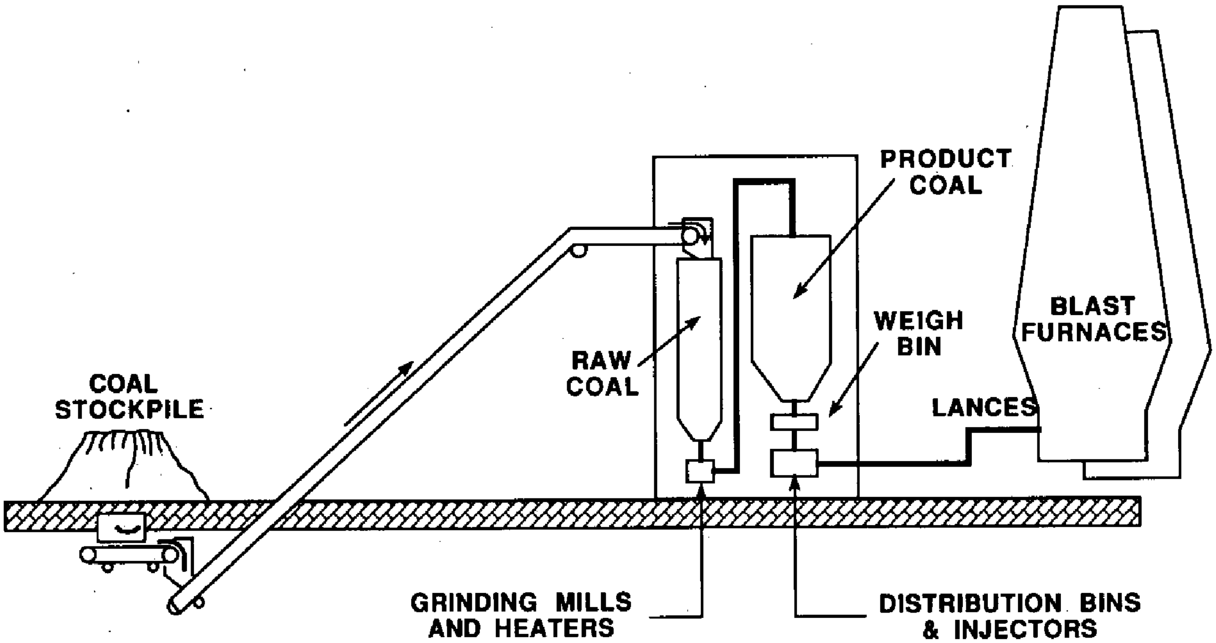
The joint development by British Steel and CPC Macawber of a process for the injection of granular coal into blast furnaces began in 1982 on the Queen Mary blast furnace at the Scunthorpe Works.(1,2) The objective of the development work was to inject granular coal into the furnace and test the performance of the CPC Macawber equipment with a wide range of coal sizes and specifications. Based on Queen Mary's performance, coal injection systems were installed on Scunthorpe's Queen Victoria, Queen Anne and Queen Bess blast furnaces and on Blast Furnaces 1 and 2 of the Ravenscraig Works. Queen Victoria's system was brought on line in November, 1984 and Queen Anne's in January, 1985. The Ravenscraig systems were started up in 1988. The success of the GCI systems at Scunthorpe and Ravenscraig led Bethlehem to conclude that the system could be applied successfully to large blast furnaces using domestic coals.

IV. INSTALLATION DESCRIPTION

A simplified flow diagram of the coal handling system at Burns Harbor is shown in Figure 4. The Raw Coal Handling Equipment and the Coal Preparation Facility includes the equipment utilized for the transportation and preparation of the coal from an existing railroad car dumper until it is prepared and stored prior to passage into the Coal Injection Facility; the Coal Injection Facility delivers the prepared coal to the blast furnace tuyeres.

Raw Coal Handling. Coal for this project is transported by rail from coal mines to Burns Harbor similar to the way in which the plant now receives coal shipments for the coke ovens. The coal is

FIGURE 4. COAL PREPARATION AND INJECTION FACILITIES
BURNS HARBOR PLANT



unloaded using a railroad car dumper, which is part of the blast furnace material handling system. A modification to the material handling system was made to enable the coal to reach either the coke ovens or the coal pile for use at the Coal Preparation Facility.

Raw Coal Reclaim. The raw coal reclaim tunnel beneath the coal storage pile contains four reclaim hoppers in the top of the tunnel. The reclaim hoppers, which are directly beneath the coal pile, feed a conveyor in the tunnel. The reclaim conveyor transports the coal at a rate of 400 tons per hour above ground to the south of the storage pile. A magnetic separator is located at the tail end of the conveyor to remove tramp ferrous metals. The conveyor discharges the coal onto a vibrating screen to separate coal over 2 inches from the main stream of minus 2-inch coal. The oversized coal passes through a precrusher which discharges minus 2-inch coal. The coal from the precrusher joins the coal that passes through the screen and is conveyed from ground level by a plant feed conveyor to the top of the building that houses the Coal Preparation Facility.

Coal Preparation. The plant feed conveyor terminates at the top of the process building that houses the Coal Preparation Facility. Coal is transferred to a distribution conveyor, which enables the coal to be discharged into either of two steel raw coal storage silos. The raw coal silos are cylindrical with conical bottoms and are completely enclosed with a vent filter on top. Each silo holds 240 tons of coal, which is a four-hour capacity at maximum injection levels. Air cannons are located in the conical section to loosen the coal to assure that mass flow is maintained through the silo.

Coal from each raw coal silo flows into a feeder which controls the flow of coal to the preparation mill. In the preparation mill, the coal is ground to the desired particle size. Products of combustion from a natural gas fired burner are mixed with recycled air from the downstream side of the process and are swept through the mill grinding chamber. The air lifts the ground coal from the mill vertically through a classifier where oversized particles are circulated back to the mill for further grinding. The proper sized particles are carried away from the mill in a 52-inch pipe. During this transport phase, the coal is dried to 1-1.5% moisture. The drying gas is controlled to maintain oxygen levels below combustible levels. There are two grinding mill systems; each system produces 30 tons per hour of pulverized coal or 60 tons per hour of granular coal.

The prepared coal is then screened to remove any remaining oversize material. Below the screens, screw feeders transport the product coal into one of four 180-ton product storage silos and then into a weigh hopper in two-ton batches. The two-ton batches are dumped from the weigh hopper into the distribution bins which are part of the Coal Injection Facility.

Coal Injection. The Coal Injection Facility includes four distribution bins located under the weigh hoppers described above. Each distribution bin contains 14 conical-shaped pant legs. Each pant leg feeds an injector which allows small amounts of coal to pass continually to an injection line. Inside the injection line, the coal is mixed with high-pressure air and is carried through approximately 600 feet of 1-1/2-inch pipe to an injection lance mounted on each of the 28 blowpipes at each furnace. At the injection lance tip, the coal is mixed with the hot blast and carried into the furnace raceway. The 14 injectors at the bottom of the distribution bin feed alternate furnace tuyeres. Each furnace requires two parallel series of equipment, each containing one product coal silo, one weigh hopper, one distribution bin and 14 injector systems.

V. PROJECT MANAGEMENT

The demonstration project is divided into three phases:

Phase I	Design
Phase II	Construction and Start-up
Phase III	Operation and Testing

Phase I was completed in December 1993 and construction was completed in January 1995. Coal was first injected in four tuyeres of D furnace on December 18, 1994. The start-up period continued to November 1995 at which time the operating and testing program started. The testing of coals (Phase III) is expected to continue to July 1998.

The estimated project cost summary is shown in Table I. The total cost is expected to be about $191 million. Additional information on project management was presented at the previous CCT Conferences. (3,4)

Facility Start-Up

The coal injection facilities were fully started in January 1995 and by early June the coal injection rate on both furnaces had stabilized at 140 lbs/ton.(5) There were facility start-up problems in January and February, but by mid-year the coal preparation and delivery systems were operating as designed. The injection rate on C furnace was increased through the summer months and was over 200 lbs/ton for September, October and November. The injection rate on D furnace was kept in the range of 145-150 lbs/ton during the second half of the year.

In December 1995, severe coal weather caused coal handling and preparation problems that were not experienced during start-up in early 1995. The most severe problem was due to moisture condensing on the inside walls of the prepared coal silos. The moisture caked the coal and eventually blocked the injectors below the silos. As a result, coal injection on C furnace was stopped in mid-December and the coal silos were emptied and cleaned. In order to prevent condensation in the future, the top and sides of the C furnace coal silos were insulated. The D furnace silos were insulated in January 1996. The insulation has prevented any reoccurrence of blocked injectors due to caked coal.

VI. TEST PROGRAM

The objective of the overall test program is to determine the effect of coal grind and coal type on blast furnace performance. The start-up operation was conducted with a high volatile coal from eastern Kentucky with 36% volatile matter, 8% ash and 0.63% sulfur. The coal preparation

system was operated to provide granular coal throughout the start-up period.
The coal injection rates and coke rates for C and D furnaces during 1995 and 1996 are shown in Figures 5 and 6, respectively.

Initial Results with Granular Coal

The first comparison of interest was the blast furnace results with coal injection versus natural gas injection. A typical monthly operating period with natural gas is shown in Table II along with the first full month (April 1995) of coal injection on D furnace. The coke rate during the initial period with coal injection at 150 lbs/ton was 55 lbs greater than with natural gas at 140 lbs/ton. This was not unexpected. It has been established in the past that 1.3 to 1.4 lbs of coke are replaced by one pound of natural gas. The initial expectation for injected coal was that 0.8-0.9 lbs of coke would be replaced by one pound of coal. Also notable in Table II is the 44 lbs/ton slag volume increase that accompanies the injected coal practice. This additional slag volume is a direct result of the coal ash. Slag sulfur also increased from 0.87% to 1.09% due to the sulfur in the coal. In order to maintain hot metal chemistry control, the slag chemistry has been altered slightly to provide more sulfur removal capacity. Another item of interest is the large decrease in the hydrogen content of the top gas when coal is injected.

The next process benchmark that was important to operating personnel was the amount of injected coal necessary to return the furnace coke rate to the levels previously experienced with natural gas. This is shown by the September 1995 operating data from C furnace in Table II. After gaining experience with coal injection and establishing a steady operation at the coal preparation facility, an injection rate of 210 lbs/ton resulted in a comparable coke rate to the natural gas experience. The September operation is notable with regard to several process parameters. The wind rate has been reduced along with an increase in the oxygen enrichment level. Increasing the oxygen content of the hot blast resulted in a higher flame temperature which, in turn, enhances coal combustion in the tuyere zone. The flame temperature increased by 270 F with coal injection versus the previous practice with natural gas. Slag volume and chemistry have changed very little except for the higher sulfur content that is directly proportional to the increased injected coal rate. A decrease in the furnace permeability during this period is also apparent.

Permeability is a parameter used to show the amount of hot blast that is blown at a given pressure drop through the furnace. In general, a higher permeability means the flow of reducing gases through the furnace is smoother. The increase in coal injection from 150 to 210 lbs/ton caused a significant reduction in the furnace permeability. Figure 7 shows the effect of coal injection on permeability in both furnaces through July 1996. The reduction of furnace permeability is a major concern for higher levels of coal injection.

Table III shows the coals used during 1995 at Burns Harbor. The most important difference between the eastern Kentucky high volatile coal and the low volatile coals is the total carbon content. The effect of higher coal carbon content is shown with the blast furnace results from November 1994 and April 1995 in Table IV. The coke rate is about 50 lbs/ton lower with the low volatile coals compared to the high volatile coal.

FIGURE 5

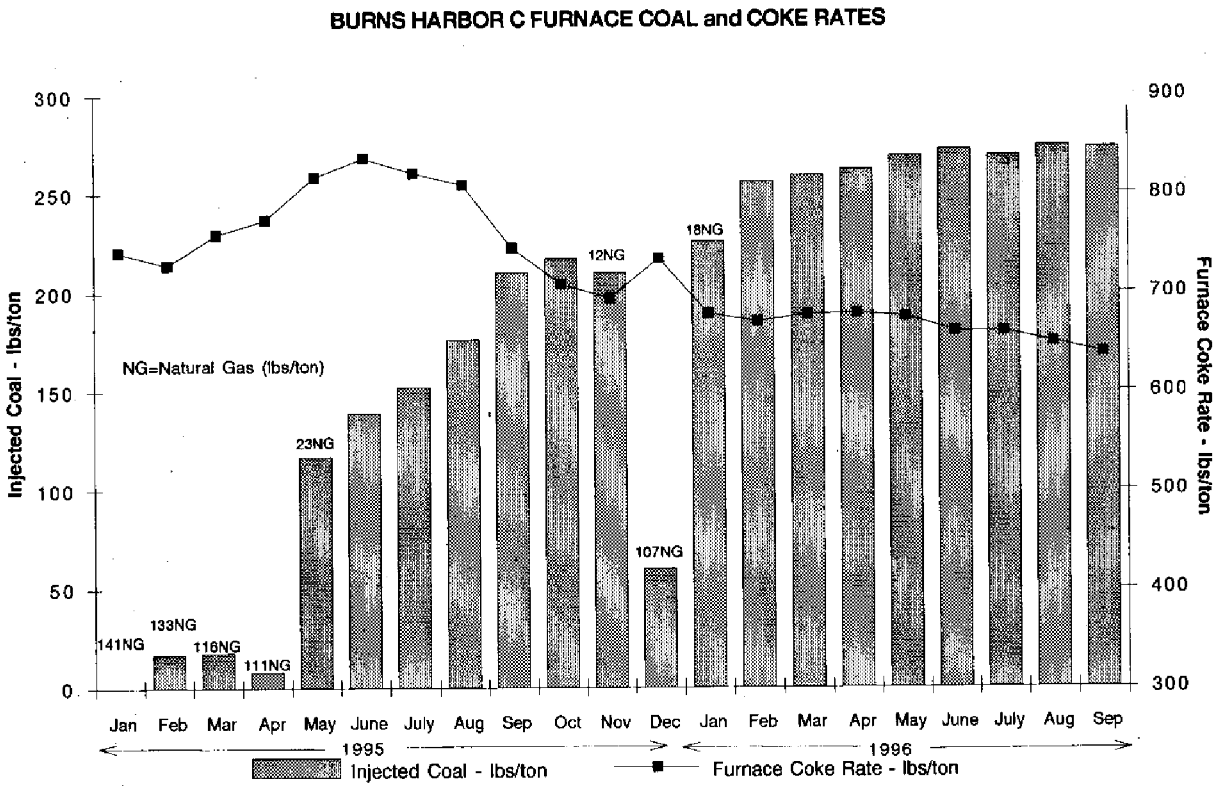


FIGURE 6

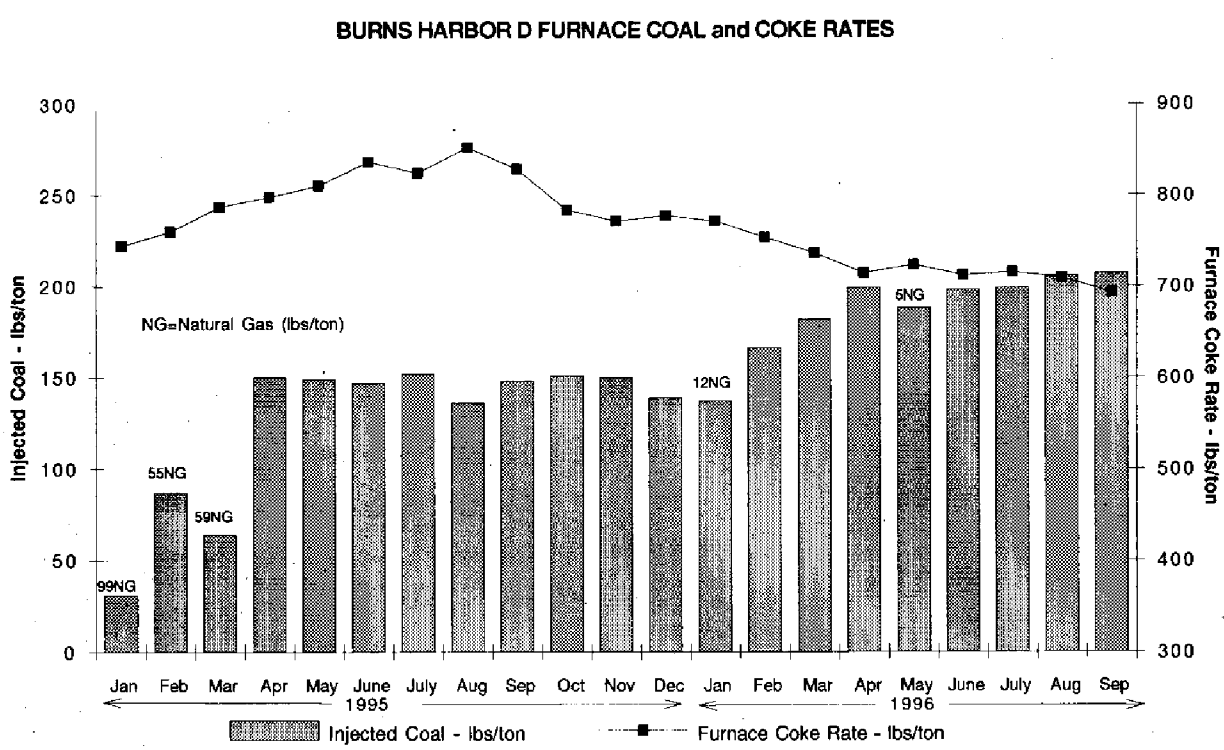
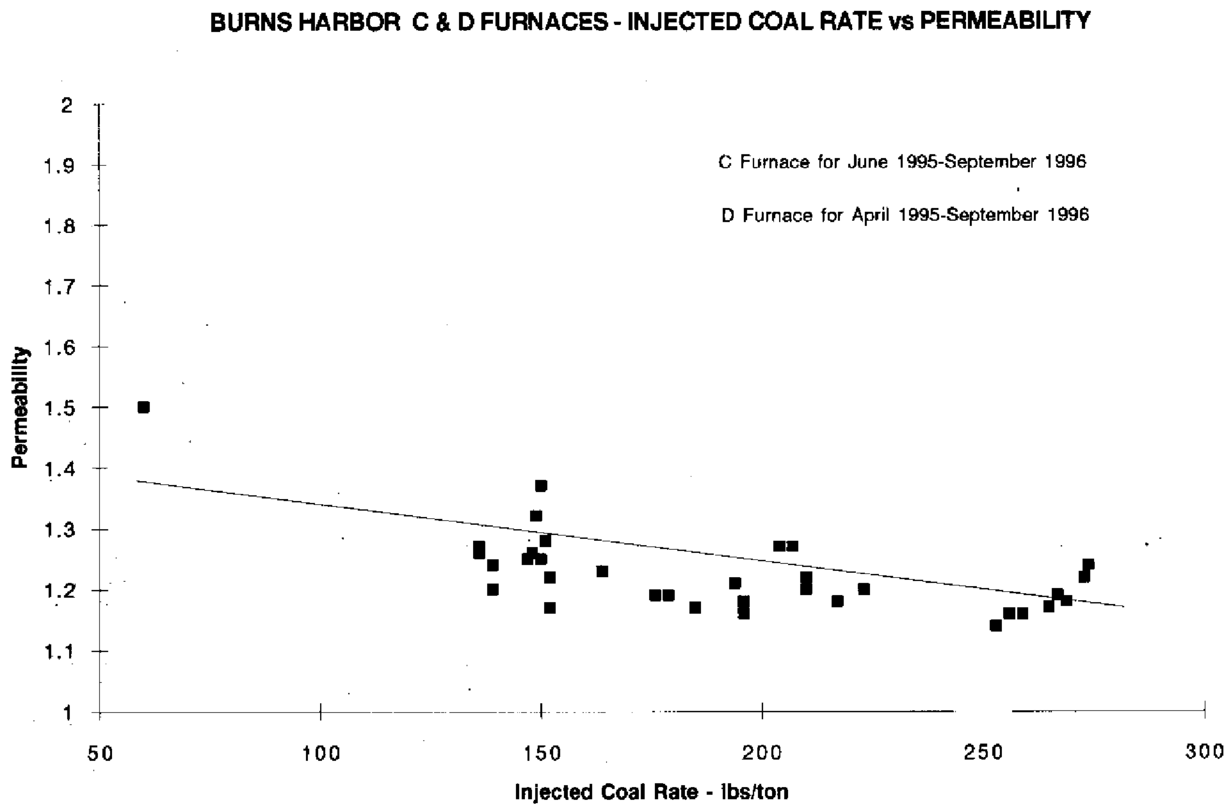


FIGURE 7


BURNS HARBOR C & D FURNACES - INJECTED COAL RATE vs PERMEABILITY
C Furnace for June 1995-September 1996
D Furnace for April 1995-September 1996
Permeability
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
50
100
150
200
250
300
Injected Coal Rate - lbs/ton

Another advantage of low volatile coal was a substantial reduction in electrical energy at the coal grinding facility due to the softness of the coal. The Hargrove Grindability Index of the low volatile coals is in the range of 90 to 101 compared to 46 for the high volatile coal.

Table IV also shows the recent operation of July 1996 using low volatile coal. The coal rate has increased to about 270 lbs/ton, the furnace coke rate has been reduced to 660 lbs/ton and the permeability has stabilized at 1.19. The lower blast pressure seen for the July 1996 period is also an indication of better furnace permeability. This was accomplished with increased use of blast moisture to produce more hydrogen in the bosh gas. This is shown by the increase in hydrogen content of the top gas. The increased hydrogen content results in a lower density bosh gas and, therefore, reduced gas flow resistance through the furnace stack.

Coke/Coal Replacement Ratio

The quantity of furnace coke that is replaced by an injected fuel is an important aspect of the overall value of the injectant on the blast furnace operation. A detailed analysis of the furnace coke/coal replacement ratio for the C and D furnaces at Burns Harbor has been completed.

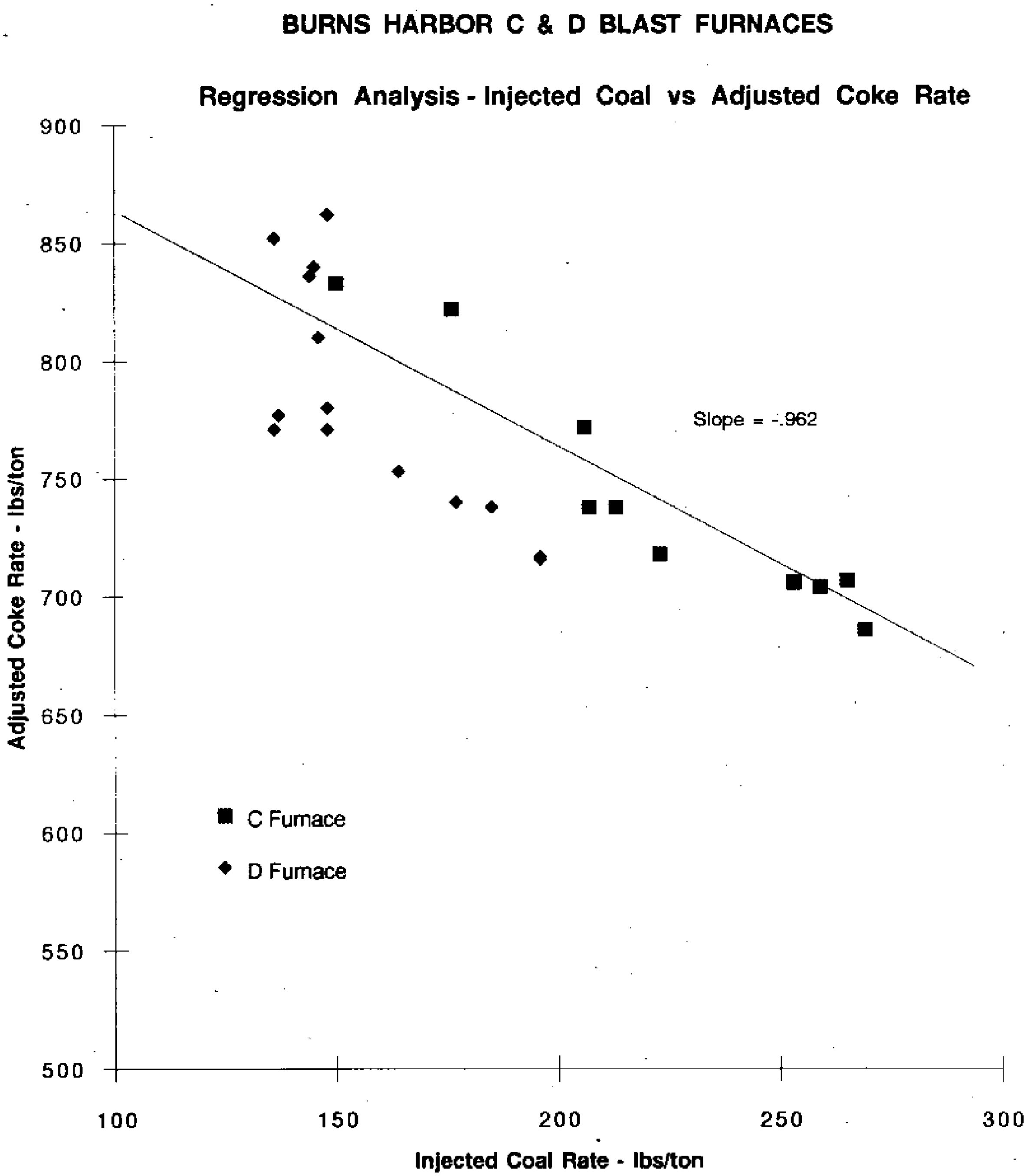
The replacement ratio for a blast furnace injected fuel is defined as the amount of coke that is replaced by one pound of the injectant. However, there are many furnace operating factors, in addition to the injectant, that affect the coke rate. In order to calculate the coke replaced by coal only, all other blast furnace operating variables that result in coke rate changes must be adjusted to some base condition. After adjusting the coke rate for changes caused by variables other than the coal, the remaining coke difference is attributed to the injected coal.

This evaluation was conducted with monthly average operating data compared to an appropriate base period for each furnace. Twenty-five months of data on both furnaces through the second quarter of 1996 were used in this evaluation.

The adjusted coke rates and the injected coal are plotted in Figure 8 along with the best fit regression line. The slope of the best fit line shows that coke/coal replacement is 0.96. This is an excellent replacement ratio and is significantly better than the 0.8-0.9 replacements reported by other coal injection operations.

The major conclusion of the test work to date is that granular coal performs very well in large blast furnaces. All other blast furnace coal injection systems use pulverized coal and some believed that pulverized coal was a requirement for large furnaces. The injection rates at Burns Harbor are not yet at the 400 lbs/ton level achieved by some, but there is nothing in the Burns Harbor experience to date that precludes higher injection rates with granular coal. The Burns Harbor furnaces will probably be limited to injection rates lower than 400 lbs/ton because of the lack of burden distribution equipment like moveable armor or a bell-less top, but this is a furnace limitation and not a coal size limitation.

FIGURE 8



BURNS HARBOR C & D BLAST FURNACES
Regression Analysis - Injected Coal vs Adjusted Coke Rate
Adjusted Coke Rate - lbs/ton
900
850
800
750
700
650
600
550
500
Slope = -.962
C Furnace
D Furnace
100
150
200
250
300
Injected Coal Rate - lbs/ton

Future Testing

The testing of different coals will continue through 1997. The first test will be with a processed sub-bituminous coal from the Encoal Corporation in Gillette, Wyoming. The Encoal operation has also been supported by the Clean Coal Technology program. About 13,000 tons of Process Derived Fuel (PDF) from Encoal will be used in the Burns Harbor furnaces for about one week.

A trial will be conducted to determine the effect of granular versus pulverized coal. The same low volatile coal that has been injected through most of 1996 with a granular size will be pulverized to 70-80% minus 200 mesh for a one month trial. This will be the first time that a direct comparison of granular versus pulverized coal will be conducted on the same blast furnace.

Additional testing to be conducted in 1997 includes a high ash content coal and a high volatile coal. The high ash content coal will be similar to the base low volatile coal in all respects except the ash. This trial will provide a unique opportunity to determine the effect of coal ash in the blast furnace process.

The test with a high volatile coal will be a direct comparison to the base low volatile coal at a high injection rate. This test along with the high ash test will provide a sound basis for economic evaluations of alternative coal sources for all U.S. blast furnace operations with coal injection.

VII. REFERENCES

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3. D. Kwasnoski and L. L. Walter, "Blast Furnace Granular Coal Injection", Second Annual Clean Coal Technology Conference, Atlanta, GA, September 1993.

4. D. Kwasnoski and L. L. Walter, "Blast Furnace Granular Coal Injection", Third Annual Coal Technology Conference, Chicago, IL, September 1994.

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TABLE I. ESTIMATED GRANULAR COAL INJECTION PROJECT COST SUMMARY

	$ Million	
Phase I Design	5.19	
Phase II Construction and Start-Up	133.85	
Phase III Operation	51.61	
Total Cost	190.65	

Cost Sharing

DOE	31.26	(16.4%)
Bethlehem Steel	159.39	(83.6%)
	190.65	

TABLE II

BURNS HARBOR BLAST FURNACE
RESULTS - NATURAL GAS COAL INJECTION

	D Furnace November 1994	D Furnace April 1995	C Furnace September 1995
Fuel Rate, lbs/ton			
Natural Gas	140	-	-
Coal	-	150	210
Coke	743	798	745
Blast Conditions:			
Reported Wind, MSCFM	171	174	164
Oxygen Enrichment, %	4.0	2.4	5.2
Moisture, Grs/SCF	6.0	16.0	8.5
Blast Pressure, psig	38.0	38.6	38.9
Flame Temperature, F	3685	3793	4062
Top Temperature, F	240	252	213
Hot Metal Analysis, %			
Silicon	.52	.56	.62
Sulfur	.040	.041	.035
Slag Analysis, %			
SiO_2	37.74	36.31	36.57
Al_2O_3	9.64	9.70	9.50
CaO	36.50	38.21	37.71
MgO	12.20	12.08	12.31
Sulfur	0.87	1.09	1.19
Slag Volume, lbs/ton	393	437	437
Furnace Permeability	1.52	1.50	1.30
Top Gas Analysis:			
H_2,%	7.33	3.05	3.13
BTU/SCF	92.8	82.6	88.1

TABLE III

COALS USED AT BURNS HARBOR IN 1995

Coal	Eastern Ky. High Volatile	Virginia Low Volatile	Virginia Low Volatile	W. Virginia Low Volatile	W. Virginia Low Volatile
Vol. Matter, %	36.0	18.0	19.6	16.5	18.4
Ash, %	7.50	5.30	5.16	5.75	5.50
Sulfur, %	0.63	0.80	0.75	0.58	0.77
Moisture*, %	3.0	1.5	1.5	1.5	1.4
Gross Heating Value, BTU/lb	13900	14900	15029	14550	14775
Hargrove Grindability Index	46	100	101	94	90
Ultimate Analysis, %					
C	78.0	87.0	87.0	86.0	85.3
O	7.00	1.40	1.52	2.20	3.07
H	5.4	4.4	4.2	4.2	4.0

* After drying and grinding

TABLE IV

BURNS HARBOR C FURNACE RESULTS WITH COAL INJECTION

	September 1995	November 1995	July 1996
Coal Type	High Volatile	Low Volatile	Low Volatile
Fuel Rate, lbs/ton			
Coal	210	210	269
Coke	745	694	660
Blast Conditions:			
Reported Wind, SCFM	164	163	154
Oxygen Enrichment, %	5.2	4.6	5.6
Moisture, Grs/SCF	8.5	7.6	16.3
Blast Pressure, psig	38.9	39.4	38.6
Flame Temperature, F	4062	3996	3949
Top Temperature, F	213	210	244
Hot Metal Analysis, %			
Silicon	.62	.45	.49
Sulfur	.035	.041	.039
Slag Analysis, %			
SiO_2	36.57	37.26	37.04
Al_2O_3	9.50	8.73	8.91
CaO	37.71	38.17	38.56
MgO	12.31	12.28	11.94
Sulfur	1.19	1.25	1.31
Slag Volume, lbs/ton	437	428	434
Furnace Permeability	1.30	1.26	1.19
Top Gas Analysis:			
H_2%	3.13	3.15	4.31
BTU/SCF	88.1	84.1	89.7